Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	|	
	|	
INQUIRY REGARDING CARRIER CURRENT SYSTEMS, INCLUDING BROADBAND OVER POWER LINE SYSTEMS	|	**ET Docket No. 03-104**

PowerComm Systems, Inc., hereby respectfully submits its reply comments in response to the *Notice of Inquiry* (the NOI), FCC 03-100, released April 28, 2003, 68 Fed. Reg. 28182; *corrected* 68 Fed. Reg. 32720, which requested information on the current state of Broadband Power Line (BPL) technology.

Summary

- The ARRL in their Comments to the NOI pointed out problems with RF noise radiating from distribution circuits. We explain how Access BPL deployment will identify, locate, and help clean up these problems.
- The ARRL in their Comments to the NOI suggested that deployment of Access BPL would not conform to FCC radiation limits and could not co-exist with Licensed services without interfering. Based on measurements of emissions from several geometries of three phase circuits, we show that the power spectral densities of –65 dBm per Hertz for transmitted Access BPL signals satisfy existing FCC rules for carrier current systems.

  We explain how both In-house and Access BPL systems, which conform to the HomePlug Alliance (HPA) transmit spectral mask, intelligently avoid interference by turning off selected carriers of their multi-carrier transmitters.
- The ARRL in their Comments to the NOI pointed out that present test methods and specifications are inadequate for BPL systems. To the contrary, we believe that our BPL system

satisfies the emissions limit with measurements specified for carrier current systems as presently defined.

- We agree with the UPLC in its Comments to the NOI that first generation Access BPL systems can satisfy the current FCC rules for radiated emissions. Based on measured emissions and comparison with all present rules, PowerComm Systems believes its system, which makes use of HomePlug Alliance compliant transceivers both for in-house and for access devices, complies with rules governing carrier current systems.

  However, future systems operating at frequencies above 30 MHz are not covered by carrier current system specifications, and the Digital Device specification will not apply due the 10 meter testing distance.

- In order for access BPL systems to be deployed to Rural America most cost effectively, revisions to FCC rules for next generation systems are needed. Extending loop reach between regenerators is the key to keeping costs down. Based on measurements of noise background in rural areas, Access BPL systems can make use of spectrum from 4 to 87 MHz most efficiently. One way to keep costs down for rural deployments is greater use of spectrum. Since carrier current system definitions only cover operation up to 30 MHz at present, extending these specifications to 87 MHz would be one way to facilitate this. Increasing allowable transmit power densities in rural areas would be another means of decreasing system costs. This would mean easing the emissions limits for non-intentional radiator operation in rural areas. This could be done while still maintaining the imperative of non-interference with licensed services.

I. Introduction

1. PowerComm Systems, Inc. would like to address some areas concerning Access BPL status which it feels have not been clearly represented by earlier Comments to the NOI. Several concerns raised by the ARRL have not been answered. It is our intention to address many of these concerns. Specifically, we want to describe measurements and methodology for evaluation of emissions from distribution circuits used for Access BPL systems. We explain our basis for interpretation of existing FCC rules. We will present our compromise field methods used to establish conformity with the rules, based on measurement of emissions from several configurations or geometries of power lines. The effects of radiation limitations and transmitted power level on the maximum "ideal" bit rate achievable over a distribution circuit will be explained. We will also discuss channel capacity estimates that have been made for a three phase feeder which we have studied extensively. Power spectral density limits for Access BPL transmitters, which we believe assure compliance with present FCC emission limits, will be presented.

2. PowerComm Systems, Inc. is focused on Access BPL solutions for Rural America. We have been working on the problems for more than 6 years. PowerComm Systems started investigating the possibilities of providing BPL as early as 1996. In January, 1997, a technical trial was initiated with the Nashville Electric Service in Nashville, TN, for the purposes of evaluating feasibility. This was assumed to be representative of an urban environment. In August, 1997, a similar technical evaluation was undertaken with the assistance of the Fayetteville Electric Service of Fayetteville, TN. This is a rural community with a population of about 25,000. The customer density over the service area is only 9 per mile. Connections in this case were made out of a rural substation along a 13.8 kV, three phase feeder for almost a mile without loads or branches. This also included three phase drops along the feeder for about 5.5 miles. This test platform still has the original connections in August of 2003. No complaints or problems have been reported to the utility or by the utility concerning these connections over the past 6 years. For both of these technical trial locations noise data was recorded, transmission properties were gathered, and the data gathered allowed channel capacities, or maximum theoretical data rates, to be estimated. Many different configurations for the three phase and neutral conductors are represented along this distribution circuit. Extensive radiated emissions tests were also conducted and these will be described below.

3. Since the first trials we have visited many other utilities and have gathered data on systems ranging from 4 kV up to 36 kV in both urban and rural settings. We have also characterized both overhead and underground distribution circuits. We have an extensive data base of information on both circuit loads and individual devices. We have also created some elaborate computer models based on the measured data for use in understanding Access BPL systems.

4. We first presented our research before the UTC's Powerline Telecommunications Forum meeting in May, 1999. This was further presented at the IEEE SoutheastCon in April, 2000. That early work entitled "BROADBAND COMMUMICATIONS OVER A RURAL POWER DISTRIBUTION CIRCUIT" is presented here as Appendix A. It summarizes the problems which had to be solved and gives partial solutions to realization of an Access BPL system. The paper points out the need to turn off transmitters at critical licensed frequencies in the useable spectrum needed for BPL. The Amateur Radio Service frequencies are listed explicitly as some to be avoided. Channel capacity for a three phase feeder operating at 7.9/ 13.8 kV is analyzed. The conclusion is that eventually Access BPL

systems could "ideally" deliver up to 200 Mbps, especially in Rural areas. Other topics covered in that preliminary work include: practical transmission power limits for Access BPL, best choices for frequencies of operation for Access BPL, some typical noise background on the power line, and signal to noise ratios to be expected. Demonstration of the feasibility of the broadband communications is established by creating a full-duplex, 2 Mbps, IP connection over the 13.8 kV distribution circuit. RF channels at 17 and 83 MHz were used for the two directions of communication.

5. This work has led to the filing of three US patent applications, two of which have been granted and a third which is still pending. These form the basis of the BPL Access systems developed by PowerComm Systems, Inc. In order to couple to the distribution circuits, unique couplers using lightning arresters were created (US Patent No. 5,864,284) to connect to the high voltage lines. This use of an existing power line device provides a very cost effective means of bypassing the distribution transformer at the customer premise. Several other system aspects of the Access BPL system including use of the neutral conductor as a ground return path along with one or more of the phase conductors was covered in US Patent No. 6,040,759. This allows the data signals to be differentially driven into the transmission line with little chance for leakage to earth. This reduces emissions from the lossy transmission line. Some other details for Access BPL system operation explained in this patent were: use of filters for isolation of power loads for the RF signals, use of similar devices on power pole ground conductors below the neutral to prevent signal leakage to earth ground in order to maintain balance and reduce radiated emissions, and use of DMT/FDM modulation, which is identical with OFDM, as the preferred modulation method. This modulation method has inherent immunity to impulse noise and allows for some of its multiple carriers to be turned off to prevent interference. The pending patent application covers methods and apparatus for range extension of Access BPL systems including: repeaters, regenerators, and converters for use in an Access BPL system.

II. Customer trial experience

6. PowerComm Systems currently has a trial underway with the Cullman Electric Co-op in Cullman, AL. CEC serves a mostly rural community. The average number of customers per mile for CEC is about 13. In this trial we have deployed Access BPL through three regenerators over a distance of 1.8 miles and passed 78 electrical customers. We have deployed BPL Internet access into 13 homes with HPA compliant access at their power outlets. We also have created wireless interfaces for utility access to the system at each of our regenerators using IEEE 802.11 standard access points. Another feature of this trial is a security/ surveillance camera that may be seen as a web cam at www.ibec.net/cam . It updates once per second and delivers its video at about 400 kbps over the 14.4/ 25 kV distribution circuit to the Internet.

7. For this trial both the in-house and the access portion of the BPL system make use of HPA compliant hardware. For the access portion of the system, since we know that our couplers introduce about 10 dB of loss, we deliver about –65 dBm/Hz onto the power line. The HPA spectral mask which turns off ARRL frequencies is used throughout the system. In fact the HomePlug Alliance undertook extensive tests with the invited participation of the ARRL. All HomePlug compliant devices bear the statement of the FCC rules concerning radiative interference – no licensed service shall be interfered with and all unlicensed service devices must accept interference from licensed service devices. Devices that operate according to the HomePlug specification are very intelligently programmed with this in mind. They constantly look for energy received in the licensed frequency bands and when detected they automatically stop communications by turning off carriers used in those bands. The incremental frequency control is approximately 200 kHz blocks as defined for the OFDM used by HPA which uses about 79 separate carriers over the band from about 4 to 20 MHz. Trial

deployments by PowerComm Systems presently use HPA compliant devices to drive the medium voltage line as well as in-house wiring. So, the entire system intelligently operates to avoid interference.

8. Radiated emissions were recorded prior to installation of trial equipment in an effort to assure compliance with FCC rules. The rationale for this will be explained below. No complaints have been received by Cullman Electric during the 9 months of testing and operation of the trial.

III. Noise from Power Distribution Lines and BPL

9. The ARRL in their Comments to the NOI pointed out some problems they have experienced with RF noise radiating from distribution circuits. This has been a problem even before Access BPL is introduced, and the suggestion is that Access BPL will tend to make this problem worse.
From our experience of observing noise from many utility circuits, there are noise problems that need fixing. We have observed noise, that shows up while probing the circuit with our couplers and simultaneously observing radiated emissions with an antenna, and the combined observations point to the conclusion that the noise is from the utility plant. The following recordings taken from power lines demonstrate the problem.

10. Access BPL deployment will help solve these and other similar problems. PowerComm Systems has examined each distribution circuit for noise quality prior to making connections with BPL equipment. In the cases shown below, we had to explain that the noise was too severe for our BPL system to work effectively, and that the utility needed to take corrective action. So, to the contrary, BPL deployment can actually help identify and solve noise problems originating from electric systems which decide to deploy Access BPL. It will be in everyone's best interests to clean up these spectrum polluters.

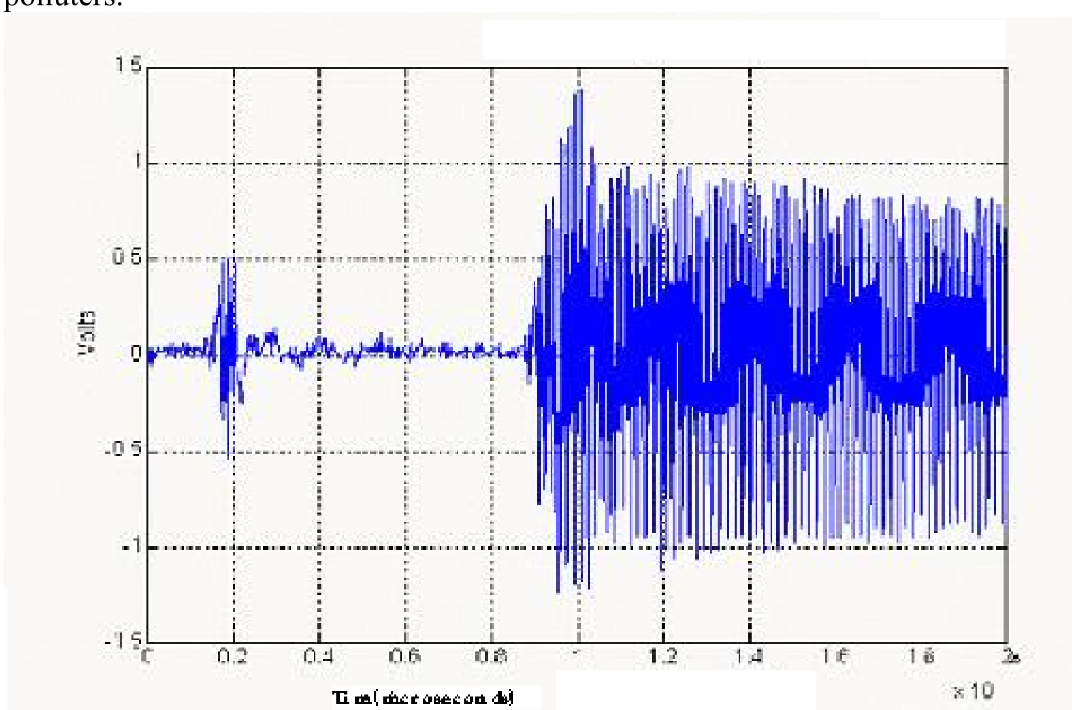

Figure 1. Voltage versus time for a Noise signal with impulses on a 7.2/13.2 kV overhead circuit

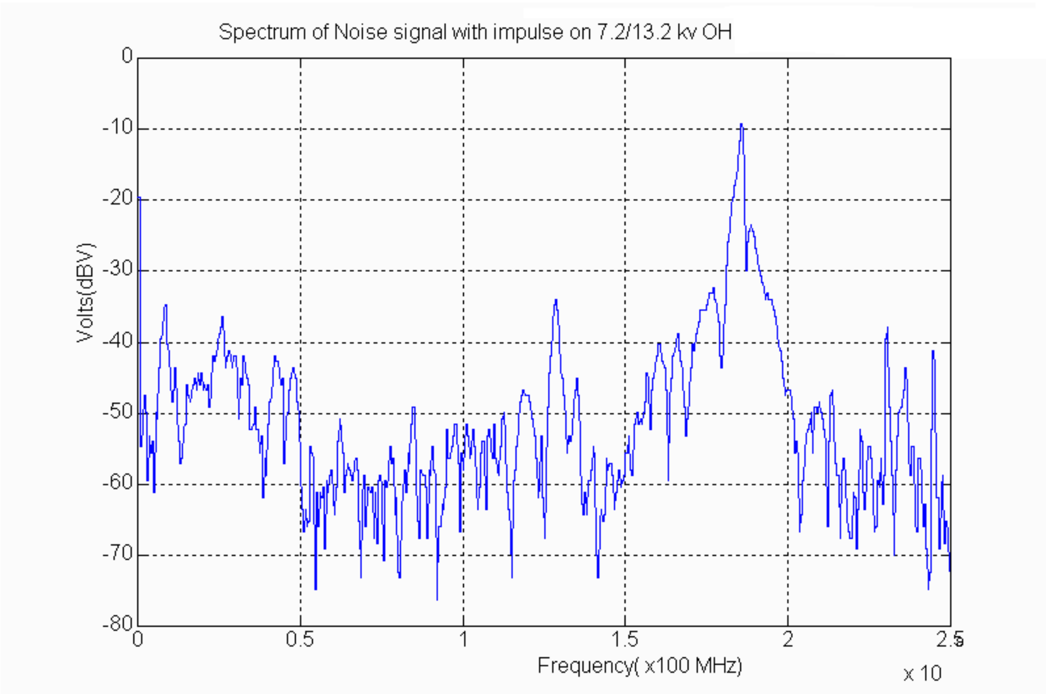

Figure 2. Power spectrum of Noise signal with impulses. Peak occurs near 180 MHz.

11. The large impulse of Figure 1 bursts out radiation centered on about 180 MHz. The entire spectral floor is also raised, especially from about 10 MHz up to around 50 MHz. The entire FM band that is usually a good marker, is entirely hidden under this impulse's energy. The small impulse in the time record would be spanned by forward error correction coding and would not disrupt a BPL system. However, the large impulse sprays out energy far beyond FCC radiation limits, and would at the least cause data disruption in a BPL system. Nearby licensed services operating at frequencies close to 180 MHz would likely be disrupted.
This noise source had to be cleaned up.

12. These noise records are observed through a coupler attached to a 7.2/ 13.2 kV overhead distribution circuit. The noise records shown in Figures 3 and 4 are not as severe as those above. Impulse has amplitude on order of the cumulative background noise. However, It's duration is greater than a microsecond and its spectral content is bothersome.

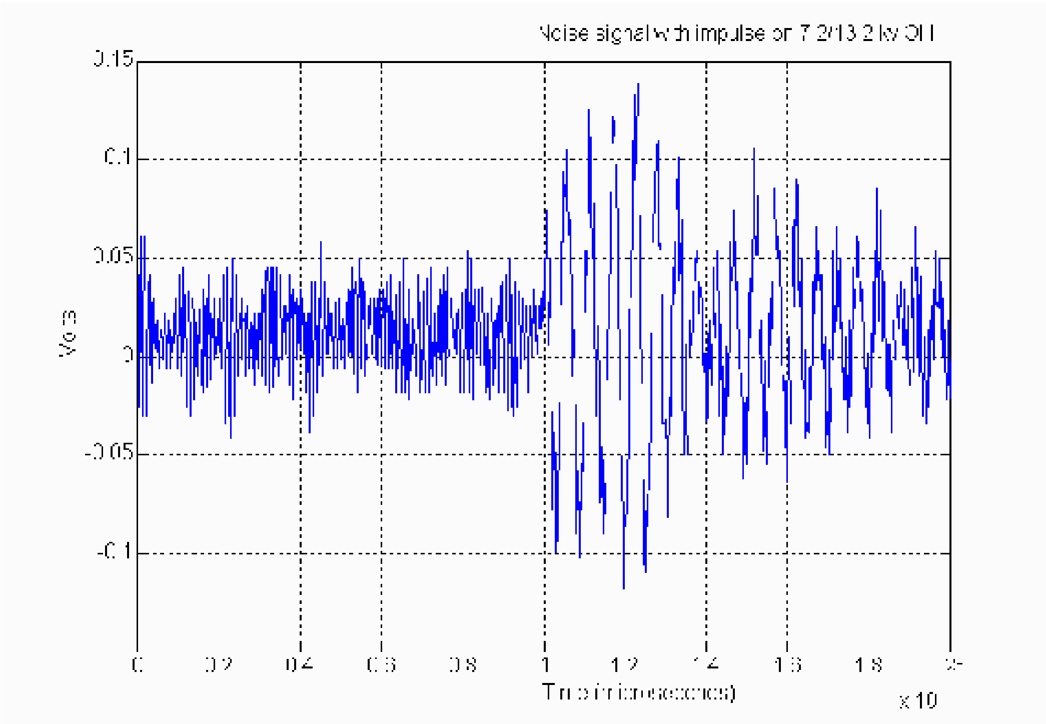

Figure 3. Voltage versus time for a Noise signal with impulse on a 7.2/13.2 kV overhead circuit

13. The energy of the impulse is concentrated near 20MHz and tends to dominate the HPA band from 4 to about 21 MHz. Other signals seen in the spectrum are TV Channel 6 at 83 MHz, the FM band from about 87 up to about 107 MHz, and TV Channel 12. Notice the relatively empty spectrum from about 40 MHz up to about 82 MHz. This entire band was unused in this region of power company operation. This spectrum could possibly be used for an access BPL application in this particular service area.

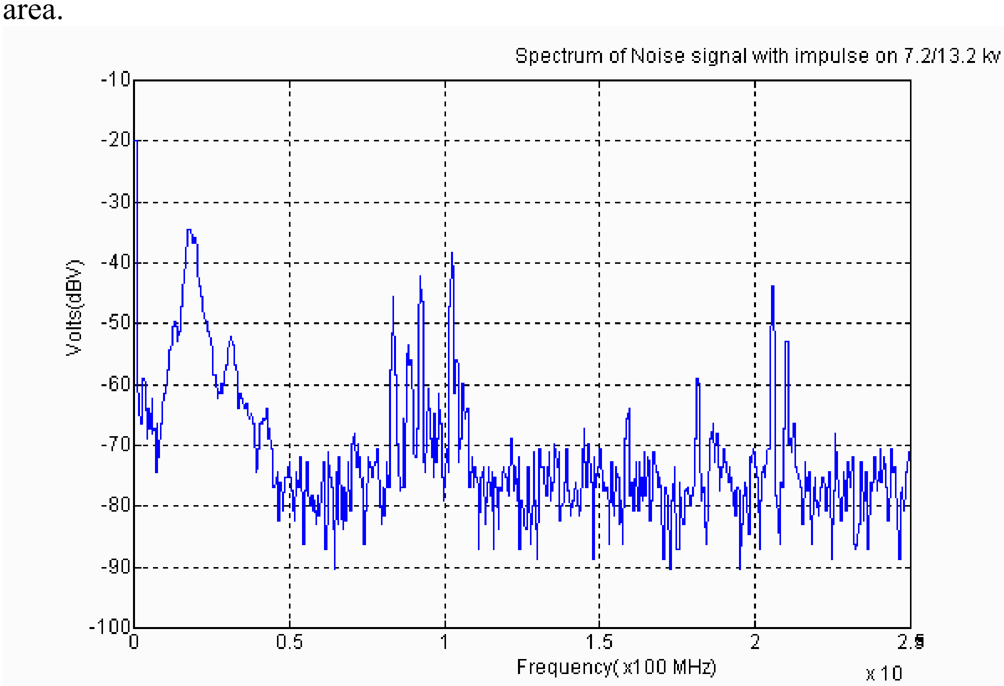

Figure 4. Spectrum of Noise Signal of Figure 3.

14. Again it should be emphasized that an Access BPL deployment would identify these noise problems. The BPL system vendor would by necessity help identify the sources of the noise, and help the utility to clean up these problems before deployment of a system. Further, once a system is in place, it is highly likely that degradation of performance of the BPL system will trigger a search for the cause. Noise sources will be much easier to identify, locate, and clean up with a Access BPL system in place.

IV. Radiated Emissions Measurements

OUTLINE

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- Summary and Suggestions for New FCC Rules for
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FCC Rules and Interpretations

15. PowerComm Systems has made power line emissions measurements has attempted to determine Access BPL operations that comply with the existing FCC Regulations and Measurements standards. We have attempted to perform our measurements and analyses consistent with interpretations of the Rules presented in the recent EPRI report number 1001891, "The Possible Use of the Electric Power Transmission/ Distribution System as a Waveguide for a Wideband Communications System", November, 2001. The interpretations used to define the broadband communication system in the EPRI report separates operation by frequency around 30 MHz. Below 30 MHz the problem is equated with that of a Carrier Current System and treated as a non-intentional radiator. Above 30 MHz the problem supposedly should be interpreted as a Class A Digital Device. Under these interpretations it is further indicated in the EPRI report that the measurements for emissions would be made with a receiver with 9 kHz bandwidth below 30 MHz, and with one of 120 kHz bandwidth at or above 30 MHz. We believe these represent the most prevalent interpretations of the FCC rules and test methods.

Near field versus Far field Radiation

Artificial line with couplers, an example of a small radiator for reference

16. Prior to making field measurements on the energized power line, a power line lab model was created and tested for emissions for reference. The model consists of two six-foot pieces of AWG2 ALS separated vertically by 42 inches. This model intends to simulate a medium voltage single phase line rated for operation typical of systems with 10kV to 15 kV phase to neutral. To interface RF signals with the line, unique couplers based on lightning arresters are mounted on each end of the model. A special terminating load with resistance approximating the characteristic impedance of the power line is placed across the artificial line in order to make it appear very long. Signals were injected at one end

and received from the other in order to measure the gains of the couplers. This “artificial line” was driven with QPSK data signals at 54 MHz, with bandwidth of 1MHz, and the antenna was used to monitor emissions from the line and couplers. The antenna was oriented parallel to the line and at a level horizontal with the middle of the line. The antenna was located at various distances away from the line and output voltages were recorded. Calculations were made to result in E-field measurements versus distance. The results of these measurements were that the small artificial line with couplers exhibited a nearly ideal log-linear response over the full range of distances, or log E varied as 1/d, as expected for far field radiation. The voltage input to the coupler was set such that the electric field intensity from the model line was about 30 microvolts per meter at 30 meters. The resulting plot of radiation versus distance for this simulated line is plotted for reference and comparison with the data from various configurations of energized power lines, as will be shown and discussed below.

Equipment and practical Test method

17. Since the test methods for evaluation of distribution circuit emissions are not specifically defined in the FCC rules, tests were designed to approximate the intentions of the existing rules. First a calibrated biconical antenna was selected. An EMS 3104C, with bandwidth of 20 to 200 MHz was selected. An 8-foot fiberglass ladder was used as a stand for mounting the antenna. This placed it at a height of about 3 meters. For mobile measurements, the ladder with antenna were mounted in the bed of a pickup truck. This placed the antenna at about 4 meters above ground.

18. A coaxial cable was connected down from the antenna into a broadband amplifier with gain of about 29 dB. The amplifier was then connected to a digital oscilloscope with FFT spectrum analysis functionality. The coax was terminated at the scope with a 75 ohm load. The scope sampled at 1 Gsps and had resolution of 500kHz per FFT cell. Portable power was supplied using a battery and power inverter. All equipment was floated from earth ground.

19. The power line varied in height, but averaged about 9 meters above earth. In all measurements the antenna was placed with its axis parallel with the power line and rotated slightly for maximum output voltage.

20. Couplers based on US Patent 5,864,284 were connected to the distribution circuit. These effectively provide capacitive coupling to the power line through lightning arresters with ferrite tuning elements. The couplers were driven using coaxial cable to eliminate the vertical component of radiation up the power pole. One set of couplers was located at a substation where the three-phase circuit configuration has a box pattern. The circuit transitions to a flat horizontal geometry out to the first pole about 90 meters away. Isolation filter devices were clamped onto the power line and neutral conductors on the substation side of the couplers. Other filter devices were clamped onto the pole ground conductor just below the neutral conductor, to maintain balance of the transmission line and to prevent the RF signals from leaking to earth. At a distance of about 4500 feet from the substation a second set of couplers was mounted. This was located near a 90 degree bend in the circuit at which the line takes on a vertical configuration. On the other side of this second set of couplers the distribution circuit takes on a triangle over neutral pattern.

21. Antenna output voltage measurements were taken at 30 MHz and 85 MHz. Measurements were taken with the antenna moved in increments from directly under the line out to a distance of 30 meters on either side of the line. Antenna output voltage measurements were scaled consistent with the test frequency and bandwidth for the measuring equipment in order to allow calculation of measured E-field intensity.

Radiation patterns versus distribution circuit Configurations - Horizontal, Vertical, Triangle over Neutral, and Box

22. Since the real power lines are very large compared with the wavelengths of the RF signals to be used with BPL systems, behavior of their radiation patterns are hard to predict. In order to determine the likely behaviors and to establish transmit power limits for BPL systems with respect to emission limits, radiation measurements were made from several three phase power line geometries: box, horizontal, vertical, and triangle over neutral. Another important aspect of these measurements was to establish the reach of the near field from the large power lines, and determine the likely distance for standard measurements to ensure that true far field radiation is measured. This will be seen in the E versus distance plots below as compared with the reference curve obtained from the artificial line. Initially, transmit signal level is set at the value required to drive the artificial line to obtain 30 microvolts per meter at 30 meter distance.

23. The figures below show one set of measured radiation versus distance data taken at 30MHz from the 13.8 kV distribution circuit. This set is for the horizontal configuration of the power line. Each curve results from applying the transmitter to a single phase one at a time. It is clear that the radiation pattern does not become log-linear as compared with the artificial line response until near 20 meters. This means that at closer distances, measurements are affected by near field as well as radiation field. Near field energy is reactive in nature and varies as $1/d^2$ and $1/d^3$. This represents inductive and capacitive effects of the power line circuit and the energy of this field stays near the power line. It is clear from this that measurements can not be made within 20 meters of the power line and be representative of radiative emissions. Extrapolation factors for change of distance are not applicable within 20 meters of this line for the horizontal configuration. This distance varies with power line configuration.

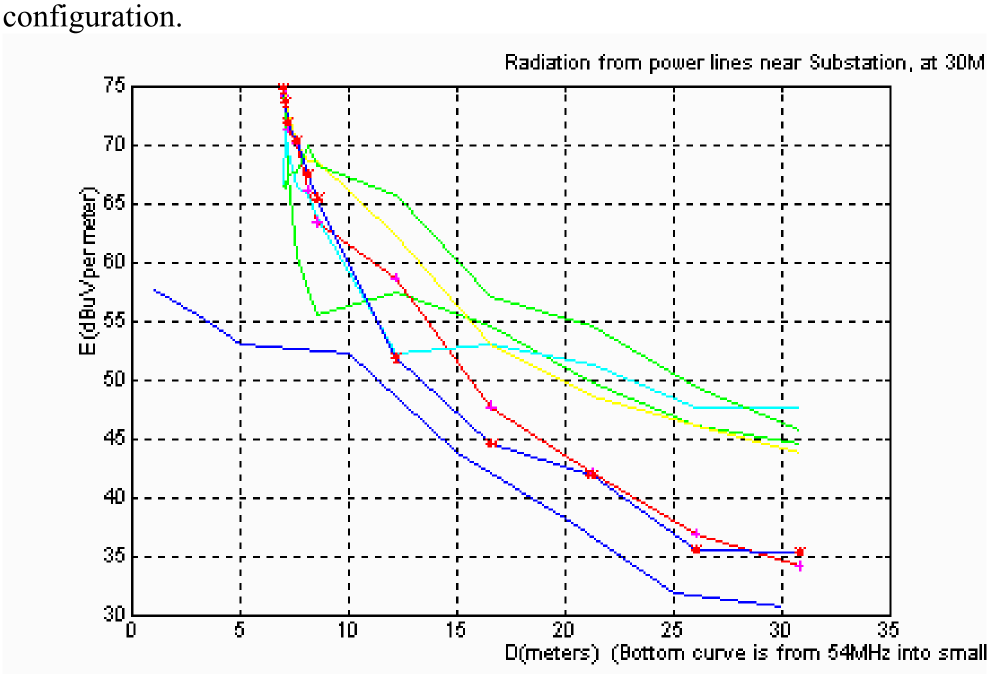

Figure 5. E-field Intensity versus distance from power line, Horizontal configuration.

24. Figure 6. shows how the measured data may be scaled to force convergence of the data at a distance of 30 meters. This would be done by varying the input drive voltage. This allows

an estimate for the range of input drive power density that will satisfy the FCC radiation rules. In this case the input drive voltage must be adjust to deliver power density in the range of –54.4 dBm/ Hz to –64.9 dBm/Hz. A transmitter signal power density applied to the power line of no greater than –65 dBm per Hertz will satisfy the emissions limit for all combinations of signal drive for this configuration. The vertical and triangle over neutral configurations are also satisfied by this limit.

25. Because of the measurement bandwidth change defined at 30 MHz from 9kHz to 120 KHz, an abrupt change occurs in the definition for radiated emissions limits for broadband signals. For broadband signals with spectra spanning this arbitrary frequency, some abrupt penalties kick in. The transmitter spectral density must be decreased abruptly by 11.3 dB for signals at 30 MHz and above in order to maintain the same total emission intensity value as below 30 MHz. This is a severe penalty for the broadband communications system due to the Test standards. The FCC measurement standard should be revised to account for emissions from broadband signals with spectra crossing this artificial boundary defined at 30 MHz. The measurement standards need to be revised for use of broadband signals of BPL systems and specified in terms of E-field density, rather than a fixed intensity with bandwidth of the receiver specified, and changed abruptly at some arbitrary frequency. In addition, to account for the expected easier radiation by higher frequency signals, the E-field density should be specified as a function of frequency. A specification limit for E-field density as an inverse log-linear function of frequency seems appropriate. This requires more study.

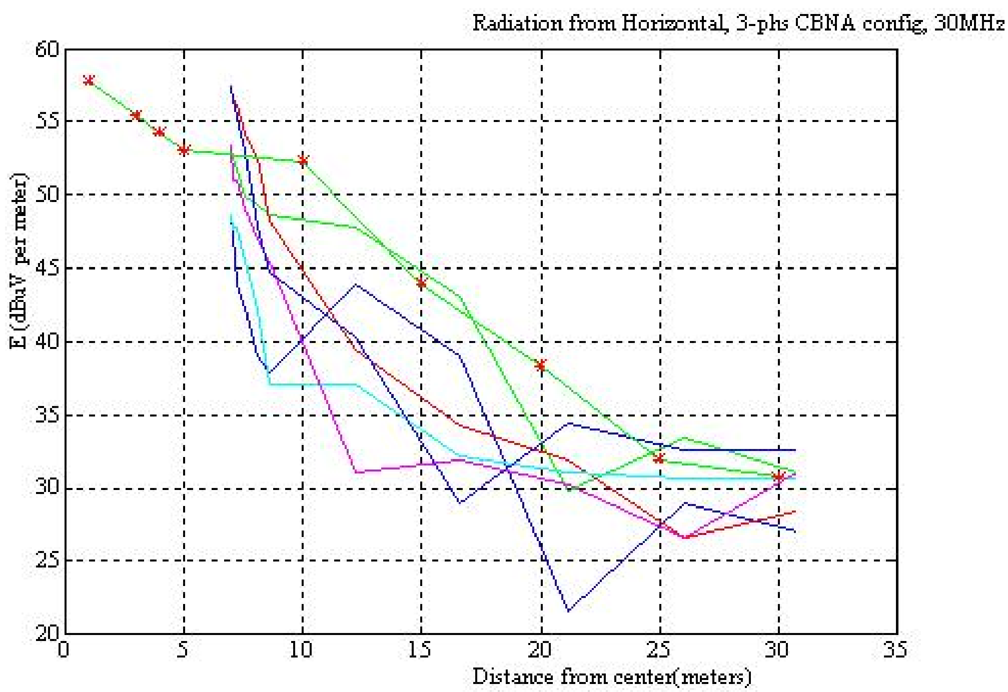

Figure 6. E-field versus distance from 13.8 kV power line
Input voltage assumed varied to result in 30 uV per meter at 30 meters.

26. Because of the reach from the power line to between 20 and 30 meters of the reactive or near field, the Digital Device emissions test may not apply. The test specification is defined for measurements to be made at a distance of 10 meters. Extrapolation to 30 meters is not valid, so before future BPL systems are developed for operation above 30 MHz, new rules must be written.

27. Table 1 summarizes the emissions results gathered from the four power line configurations. In each case the electric field intensity at 30 meters was adjusted by setting the input voltage to the coupler so that 30 uV per meter would be seen by the antenna. This voltage level was then converted to an equivalent input power density in dBmW per Hertz. The worst case, or least power spectral density for the transmitted signal, for each configuration and each direction away from the power line, is listed in the table.

28. The data from the Box configuration appears to be dominated by near field directly from the nearby couplers and signal injection. This case has been worked in order to improve overall system performance since this data was gathered. Neglecting this case, the transmit power density limit below 30 MHz appears to be about –65 dBm per Hertz. The transmit power density limit from 30 to 88 MHz is even lower at around –80 dBm per Hertz. (Recall that 11.3 dB of this difference is due to the abrupt change in Measurement bandwidth definition at 30 MHz.)

TABLE 1. Transmit Power Spectral Density Limits for an Access BPL system

(Due to radiated emissions from a three phase, 13.8 kV distribution circuit, from various geometries)

Frequency		**below 30 MHz**	**30 MHz and above**	**85 MHz**
Configuration			**(dBmW per Hz)**	
Horizontal	**north**	**-64.9**	**-76.2**	**-72.5**
	south	**-61.4**	**-72.7**	**-82.**
Vertical		**-53.7**	**-65.0**	**-65.9**
Triangle over neutral		**-65.5**	**-76.8**	**-67.6**
Box	**north**	**-73.2**	**-84.5**	**-95.1**
	south	**-72.7**	**-84.0**	**-98.6**
		(Measurement BW = 9 kHz	**= 120kHZ)**	

Notes: ,The transmit power limit below 30 MHz appears to be about –65 dBm per Hertz.
The transmit power limit from 30 to 88 MHz is even lower at around –80 dBm per Hertz.
The Box configuration data is contaminated by Coupler reactive field energy. This has been addressed in more recent installations, but remains an area for research.
(Recall that 11.3 dB of this difference is due to the abrupt change in Measurement bandwidth definition change at 30 MHz.)

Standing Waves as seen under the distribution line and possible hot spots

29. Measurements were taken of E-field intensity directly under the power line starting at the substation and going out along the line. The line starts out in the box configuration and goes through transitions immediately, so that at the first pole about 90 meters away, the line conforms to a horizontal configuration. From the figure below it can be seen that the E-field intensity drops by 10 to 15 dB at 30 MHz within 60 meters of the starting pole. These decreases are not due to line losses, but are much more likely due to distancing from the couplers as hot spots. A strong case can be made for the couplers as near field hot spots that may be worked to improve radiation performance.

30. Additional data was also taken at finer spacings along under the line. Samples were taken at 2 meter spacings at distances of 120 to 150 meters from the couplers at the substation. Standing wave patterns are obvious in the data. The voltage maxima and minima observed varied by about a 3 to 1 ratio at 30 MHz with periodicity of 20 meters. No other "hot spots" were observed along the line. In fact the signal level falls on the lossy line and the E-field falls off in proportion versus distance along the line. The horizontal configuration data was taken starting near a voltage maxima under the distribution circuit.

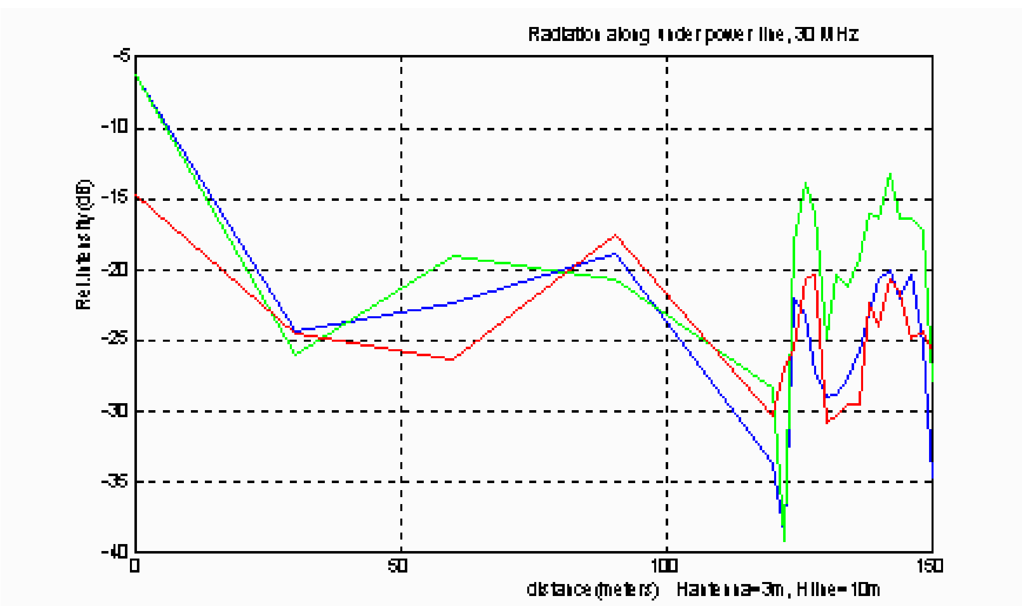

Figure 7. Relative Electric field intensity as Measured under the three phase 13.8 kV power line. Measurements were made with 5 meter spacings out to 120 meters, and with 2 meter spacings from 120 to 150 meters. The wavelength of the signal at 30 MHz is 10 meters. The standing wave pattern is apparent with the closer spaced data, with periodicity on 20 meters and VSWR = ~ 3 at this distance.

31. It is appropriate to compare these plots from those reported as simulations from the ARRL. It will be seen that measurements of E-field intensity along the power line vary as standing waves. However, the ARRL model of a lossless line over earth is not

consistent with the measured results. The line must be seen as a lossy transmission line. Paths to earth should not be assumed to exist, unless they are modeled as high impedance at the RF frequencies. The transmission line should be assumed to be driven from one end, as the opposite path direction is blocked by high loss, impedance matching filters. The transmission line should be terminated in its characteristic impedance in order to simulate a long line. The coupler must also be modeled correctly, as it is the largest source of field intensity in the system, forming a hot spot that has a large reactive field with limited radiation reach. This has been observed repeatedly and is one of our areas for continuing research.

Implications for Channel Capacities

32. The Home Plug Alliance In-House BPL modems use transmit power densities of -55 to -50 dBm per Hertz. Previously, as reported in Appendix A, it was estimated that transmit power level for Access BPL systems might be around –60 dBmW per Hertz. This was based on previous standards work in defining the VDSL TelCo communications method, which will operate over unshielded, non-twisted phone cables with carriers up to 30 MHz. Based on emissions measurements from overhead distribution circuits, lower channel capacities result for the transmit power density limits of –65 dBm/Hz, and –80 dBm/Hz above 30 MHz.

33. Tables 2 and 3 are taken in part from Appendix A. They have been augmented with lower revised power spectral density limits and capacities based on radiated emission limits and measured results.

Table 2. Channel Capacity for the First Mile Feeder

Signal Level (dBVrms)	Signal Level (dBm/Hz)	Number of Useable 1 MHz Channels	Total capacity (Mbps)
17.	-40.	90	771.
7.	-50.	74	501.
-3.	-60.	60	280.
Radiation Limited			
-8.	-65.	54	220.
-8./ -23.	**-65. / -80.**	**32**	**100.**

34. Channel capacity is an "ideal" maximum expected data rate. The values in Tables 2 and 3 assume the Access BPL signal can span all the way from 4 MHz to 130 MHz. These calculations were made assuming all ARRL frequency allocations are turned off over the 1MHz band containing each assignment. All of the FM band was excluded from the calculations.
With the significantly reduced allowable transmit power density levels, the channel capacity would be limited to about 100 Mbps on overhead distribution circuits.

35. When a more practical case of a loaded line is used in the calculations, the channel capacity is further reduced. Table 3. shows that with 5 loads per mile per phase the capacity is reduced to 50 Mbps. Shorter distances than a mile before regeneration will be required to maintain significant channel capacity. Having restricted bandwidth and restricted power density also forces regeneration to be placed at closer spacing driving up system costs. This is especially important for Rural deployments. In order to service Rural America with Access BPL some special rules need to be written to help keep system deployment costs down.

36. If the couplers can be shielded and better impedance matched to the line, this source of reactive radiation can be significantly reduced. When this is accomplished, the transmit signal levels injected onto the power line may be increased resulting in longer "loop reach" before regeneration and higher data rates. Since total power levels for Access BPL are limited to a fraction of a watt, and whereas many Licensed services are allowed powers in watts, perhaps some form of licensing is in order for Access BPL systems. Without some type of relief from the existing radiation limits, service over the long distances in Rural areas could remain too costly.

Table 3. Channel Capacity for the "Second" Mile, with 5 typical customer loads per phase per mile, and with no line conditioning.

Signal Level (dBVrms)	Signal Level (dBm/Hz)	Number of Useable 1MHz Channels	Total capacity (Mbps)
17.	-40.	72	464.
7.	-50.	57	250.
-3.	-60.	34	96.
Radiation Limited			
-8.	-65.	30	90.
-8./ -23.	**-65. / -80.**	**20**	**50.**

37. The capacities reported here are based on a single noise profile from a Rural setting. Whenever an Urban noise profile is used, with several of the VHF bands occupied, e.g. Nashville, TN, with channels 2, 4, and 5 active, and with many more licensed bands in use, the data capacities become much less. Considering that loading of distribution circuits is also greater, data rates per customer become even lower. Access BPL becomes marginally competitive with other broadband Internet services in many Urban settings. Improved Utility service is still another matter however, and since Access BPL is perhaps the only cost effective means of gathering AMR information and providing load management into homes, Access BPL still is a needed option in Urban areas.

Conclusions and Future Considerations

38. The ARRL in their Comments to the NOI pointed out problems with RF noise radiating from distribution circuits. They are of the opinion that Access BPL deployments will cause this problem to worsen. Noise sources will be much easier to identify, locate, and clean up with an Access BPL system in place. An Access BPL deployment would identify these noise problems.
The BPL system vendor would by necessity help identify the sources of the noise, and help the utility to clean up these problems before deployment of a system. Further, once a system is in place, it is highly likely that degradation of performance of the BPL system will trigger a search for the cause.

39. Based on measurements of emissions from several geometries of three phase circuits we have shown that power spectral densities of –65 dBm per Hertz for Access BPL signals satisfy existing FCC rules for carrier current systems. We explain how both In-house and Access BPL systems, which conform to the HPA transmit spectral mask, intelligently avoid interference by turning off selected carriers of the multi-carrier transmitters.

40. We agree with the UPLC in its Comments to the NOI that first generation Access BPL systems can satisfy the current FCC rules for radiated emissions. Based on measured emissions and comparison with all present rules, PowerComm Systems believes its system, which makes use of HomePlug Alliance compliant transceivers both for in-house and for access devices, complies with rules governing Current Carrier Systems. However, future BPL systems operating at frequencies above 30 MHz are not covered by present Current Carrier System specifications, and the Digital Device specification will not apply due the 10 meter testing distance.

41. Existing FCC definitions, equipment classifications, and measurement standards were not written with this application in mind. Perhaps a new class of service should to be defined for the Broadband Power Line Communications Systems that will operate over the medium voltage distribution circuits and over the low voltage drop wires into the customer premises.
This is especially a problem for next generation systems operating at and above 30 MHz.

42. Radiation limits should not change in a stepwise fashion over the operating frequency range of the broadband system at 30 MHz. The measurement standard should be consistent across the frequency spectrum of operation, with limits set as a continuous function of frequency. Radiation limits should be defined in terms of electric field density rather than total intensity in order to cover the broadband signals and noises operational for BPL communication systems.
This will result in an easier to understand and verify specification for transmit power spectral density for transceivers to comply with.

43. Broadband Internet access for Rural Americans will be most cost effectively provided through communications partnerships with the Rural Electric Co-operatives. Broadband communications over the existing power line can reach virtually all communities and homes in America. The FCC can be pro-active in making this happen in several ways. Since the costs of regeneration are the key to system deployments in rural areas, efforts to control these costs could be taken. Presently, regenerators are required about every half mile.
A BPL system backbone can be deployed at a rate of a mile per hour per bucket truck and line crew. Present day systems can be deployed at under $2k per mile or less than $200 per customer passed. Increased transmit power density is needed for greater system reach before regeneration. New rules could provide relief of the radiation density allowable in Rural areas. The first generation BPL systems

that can serve hundreds of homes will be limited to a fraction of a milliwatt of transmit power. Transmitters for individual Amateur radio operators on the other hand are afforded watts of power.

44. It should be pointed out that with proper choice of modulation method, such as DMT and FDM, or OFDM, it will be possible to easily control spectral densities used by the BPL communication system, and to comply with the non-interference with existing licensed services. This is possible due to the fine control of carriers at resolutions as low as 200 kHz as for the HPA specification. With this modulation method spectral bands may simply be turned off as they are done with the HPA standard version 1.0. Future modulation schemes could define more carriers and even closer carrier spacing, allowing tighter control over larger frequency spans.

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Appendix A.

BROADBAND COMMUMICATIONS OVER A RURAL POWER DISTRIBUTION CIRCUIT

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Abstract

Feasibility for broadband communication over high-voltage power distribution lines is shown through study of signal to noise ratio and calculation of channel capacity for a typical rural circuit. RF Powerline Carrier (RF PLC) communication consisting of 2-way TCP/IP data at 2 Mbps is described. This is especially important for rural communities world wide, since RF PLC may furnish bi-directional broadband Internet access service where none is currently available.

Introduction

Rural communities may not be serviced by broadband Internet access anytime in the near future by existing means. Service from telephone companies by digital subscriber line(xDSL) or by cable companies using cable modems will not reach out to the rural customers. One-way satellite access is available in some areas, but speeds are limited and costs will remain high without competition. Since electrical power reaches to even remote rural customers, it is thought that communications over the power lines might offer a solution to this problem. In order to determine feasibility of using the over-head power lines for RF PLC systems, it is necessary to make reasonable assumptions about the transmit signal levels, to determine models for the channel insertion loss, and to understand the noise power levels that are likely to be encountered. These issues will each be considered, and then a practical test case of a rural distribution circuit will be examined and its channel capacity estimated. Demonstration of broadband communications over the distribution circuit will be described.

Channel capacity[1] of a frequency division multiplexed communications channel is given by

$$\underset{\text{bps.}}{\text{Total capacity}} = BW * \sum_{i=1}^{\text{No. of subchannels}} \log_2(1+snr_i) \qquad (1)$$

Channel capacity depends on the bandwidth of the channel, or bandwidth and number of subchannels, and the ratio of the signal to noise powers at the receiver measured over each subchannel. The signal level at the receiver will be dependent on the transmit power level and the attenuation of the channel. The transmit signal power level for the PLC must be limited to comply with FCC or other local regulation for non-interference with other licensed services. The transmit power level must be large enough to allow the signal to propagate some reasonable distance along the power line to a receiver, or a repeater, and still maintain adequate SNR for reliable communications. The frequency dependent attenuation and phase distortion of the power transmission line must be understood and minimized over the PLC RF carrier frequencies. The noise at the receiver, which may consist of both stationary frequency domain signals and transient impulse spikes, may affect the capacity of each subchannel differently. The impulse noise will cause degradation of channel capacity in a time varying way, but its effects may be minimized by use of forward error correction techniques.

Transmit Power Levels

The regulations in the U. S. for unlicensed emitters are contained in FCC part 15 of Title 47. Levels for emissions are specified in two ways- 1) that no harmful interference to a licensed service be caused by an unlicensed emitter, and 2) that any unlicensed emitter not exceed certain frequency dependent emitted field intensities as referenced in 15.109(e) and listed in 15.209(a). Interpretations of the emission requirements and measurements methods for compliance are published in Bellcore generic specifications[2] intended primarily for use in TelCo plant. The amount of transmit power available for non-interfering use by a broadband PLC system may be an overriding issue that could ultimately determine viability under any circumstances. Such emissions measurements are required before proceeding any further with serious development of RF PLC systems. However, some insight into acceptable transmit levels can be gained by reviewing some of the existing wireline communications systems.

Typical transmit power levels for telecom wireline digital services are on the order of -40 dBm/Hz. This is the nominal level used by older T1-AMI transmitters, as well as by emerging HDSL2 and ADSL services. While T1-AMI uses spectrum up to 1.5 MHz, ADSL up to 1.1 MHz, and HDSL2 up to about 400 kHz of bandwidth, they each use about this power density. These services use twisted-pair cable at below radio frequencies and their crosstalking influence is largely restricted to services in the same bundle of conductors. Interference with the AM radio band may still be problematic from time to time, however. Their power levels of about 20 dBm might be an upper limit for the RF PLCs, if operating over 1 MHz bandwidth subchannels.

Another wired broadband service that is presently in the development stages is VDSL. VDSL[3] is the very-high bit rate digital subscriber line service that will be used over the drop wires into the residence. The drop wires are unshielded and untwisted paired cable, and therefore will be subject to some of the same radiation and induced noise concerns as for the aerial power line carrier systems. This technical specification outlines the 13, 26, or 52 Mbps symmetrical digital subscriber line proposed standard for use by Telcos. Operational frequencies are up to 30 MHz. The RF egress and ingress will be problems similar to those which will have to be overcome for aerial PLC systems. The guidelines developed for VDSL are good starting points for establishing acceptable broadband PLC systems operation.

One example of the problems that must be solved is co-existence with other radio services such as Amateur Radio. Section 6.3.1 of the VDSL technical report lists Amateur Radio Bands which will need to be avoided.

Amateur Radio Bands

1.81-2.0 MHz	18.068-18.168 MHz
3.5-4.0	21-21.45
7.0-7.3	24.89-24.99
10.1-10.15	28-29.7
14.-14.35	50-53.

In order to avoid degrading operation of these radio services, the technical report suggests power levels of no more than -60 dBm/Hz should be used by VDSL transmitters and no more than -80 dBm/Hz in the reserved bands. For the RF power line carriers, the characteristic impedance for the distribution lines will be somewhat greater than the 100 ohms used by the lines for VDSL. This would imply a smaller injected current for the same power delivered to the cable for PLCs. However, since the amount of radiated power depends on the balance of the cable pair, and the balance of the power transmission lines will be somewhat worse than for the drop wire used for VDSL, and the power levels might need to be somewhat less for PLCs. Most of the interference from VDSL has been shown to be due to the vertical drop portion of the drop-wire into the residence.[4] This can be avoided with the PLCs by terminating them at the pole, and taking coax drops into the residence. This should allow higher non-interfering power levels to used by RF PLCs. Field measurements such as those made for VDSL[5] will need to be made for proposed broadband PLCs to set realistic transmit power levels. Larger power densities might also be allowable in rural applications than in urban applications, since interference is dependent on proximity between the disturbing and disturbed services. At -60 dBm/Hz, the range of interference between VDSL and Amateur Radios is only about 60 meters according to a Bellcore simulation.[4]

As with the Amateur Radio bands, the FM radio band from 88 to 108 MHz should be avoided in all locations by the PLCs. The VHF TV channels may be useable in many locales where UHF channels dominate the broadcast TV assignments for the area. It is unlikely that PLCs will work into the UHF TV bands due to the large cable attenuation at these higher frequencies.

In order to keep transmit power levels down to a non-interfering level and at the same time maintain good SNR at the receiver, compromises such as adding repeater/regenerators along the line are common practice in communications systems. For T1/AMI the repeaters are located every 6 kfeet, while for the new 2-wire T1/HDSL2 repeater spacing is 12 kfeet. Cable television coax repeaters are used every 3 kfeet. An operational and cost trade-off can be made if the spacing between transmitter and receiver is reasonable at sufficient transmitter power levels. The attenuation and phase distortion of the power lines at the frequencies of possible operation must be understood and reduced, if possible, in order to increase the spacing.

Channel Characterization, Attenuation and Received Levels

Cable transmission lines are typically characterized by a set of four primary constants -- **R, L, G,** and **C.** Except for **C** these each are nonlinear functions of frequency. They also vary with temperature. These distributed parameters are often tabulated for a particular conductor size and configuration, and they are given in standard units per unit length. Analysis of wireline networks containing transmission lines usually starts with theseparameters.[3,6,7] For example, the VDSL Systems Requirements document has tables of primary constants for six types of drop cable characterized up to 30 MHz. Although primary constants for power cable for use at 60 Hz are available[6], there does not seem to exist similar characterization for power line cable for the purposes of RF communications. Another aspect of the characterization that it needed is the effects of the oxidation layer and skin effect on the weathered conductors.

Secondary cable parameters[6] including characteristic impedance and propagation constant are usually derived from the primary constants, and are used in transmission line network analysis. Sometimes they are directly measured. Characteristic impedance is defined by

$$Z0 = \text{sqrt} [(R+jwL) / (G + jwC)] . \qquad (2)$$

Z0 approaches sqrt(L / C) as w = 2 *pi *f increases, but it also can be shown to vary as $w^{-1/2}$ because of the nonlinear behavior of R and L at high frequencies.

Propagation constant is defined as

$$\gamma = \alpha + j\,\beta = \text{sqrt}[(R + jwL)^* (G + jwC)], \qquad (3)$$

where

α is the attenuation constant , and has units of nepers per unit length.

β is the phase constant, and has units of radians per unit length.

Phase delay is given by β / w in seconds.

Group delay is defined as dβ / dw in seconds.

Because of skin effect at high frequencies, γ can be written as

γ = K sqrt(w) + K2*w + j K sqrt(w)
+ j w sqrt(L C) . (4)

Voltage and current vary along a transmission line which is driven by, and terminated in its characteristic impedance according to

V(t,l) = Vo exp(γ * l)
and I(t,l) = Io exp(γ* l) and Z0=Vo/Io.

Skin effect dominates the losses represented by R. R increases in proportion to square-root of frequency and may also contain a term proportional to frequency at very high frequencies. This term tends to account for losses due to radiation as well as ohmic losses especially in the outer insulating material[8], or in the oxidation layer for bare cable. R can be expressed as

$R = R_{dc}$*(1.+ k1* srqt(f) + k2* f) . (5)

At high frequencies, alpha reduces to
α = R / 2*Z0. (6)
However, because of the variation of R with frequency alpha can be written as

α = K0+ K1*sqrt(f) + K2* f dB/ mile. (7)

For example, for Cat3 twisted pair cable alpha is equivalently given by[8]:

α for Cat3 = 7.1 * sqrt(f) + 0.7 * f
dB/ kfoot . (8)
The expression for α can be obtained by a curve fit to measured insertion loss versus frequency data for a section of transmission line. Resistance per unit length can then be obtained from alpha. Alternatively, the measurement method of Appendix A of [3] can be used.

L also changes with frequency and decreases due to skin effect. The inductance per unit length will decrease as $f^{-1/2}$. With C almost constant, L can be determined from measurements of delay versus frequency. Alternatively, the measurement method of Appendix A of [3] can be used.

Appendix A of the VDSL System Reference contains an excellent tutorial on network analysis useful for PLC cable modeling. The approach using the ABCD network parameters has been used for many years both in communications[7] and power transmission[6] textbooks and practice. The transmission and echo properties are derived from the use of the **A B C D** 2-port network representation and equations:

I1 --> A B <-- I2 V1 = A V2 + B I2
+ CD +
V1 - - V2 I1 = C V2 + D I2

One useful property of this network model is that a cascade of networks can be modeled by the multiplication of their **A B C D** matrices to form the equivalent network **A B C D** matrix representation.

The network matrix elements for a piece of transmission line of length len are related to **Z0** and γ by:
A = **D** = cosh(γ * len) , (9)

B = **Z0** sinh(γ * len) , (10)

and **C** = [sinh(γ * len)]/**Z0**. (11)

The input impedance seen looking into the equivalent network terminated with load impedance ZL is given by:

$$\text{Zin} = \text{V1/I1} = \frac{\text{A ZL+ B}}{\text{C ZL+ D}} . \quad (12)$$

The Insertion Loss(IL) and Insertion Phase(IP) due to the network when driven by a source with impedance ZS and terminated in a load impedance ZL is

$$\text{IL (dB)} = 20 \log_{10} \left\{ \frac{\text{A ZL+ B+(C ZL+ D)ZS}}{\text{ZS + ZL}} \right\} \quad (13)$$
and

IP (radians) = Arg(V2)-Arg(V1)
or = Arg(VL)-Arg(V across Zin). (14)

Assuming a model can be constructed that adequately represents the actual measured channel effects on a transmitted signal, then the received signal level will be given simply by

$$S = T - IL \text{ (dBm)}. \quad (15)$$

Noise Characteristics and Levels

The noise at the receiver will consist of the sum of all induced and conducted sources along the channel to the receiver. The noise induced in the open aerial power line comes from many sources, but it is for certain that all nearby broadcast radio and TV channels will show up. Sources may consist of steady frequency and amplitudes such as a broadcast FM radio signal. They could also be transient signals of constant frequency, but on-off or variable amplitude such as a keying amateur radio signal. Other noise sources may be time variable impulsive type transients, such as occur in breakover of loose connections of power system components. The noise at the receiver, which may consist of both stationary frequency domain signals and transient impulse spikes, may affect the capacity of each subchannel differently. The impulse noise will cause degradation of channel capacity in a time varying way, but their effects may be minimized by use of forward error correction techniques.

Several years ago EPRI looked at the noise environment of distribution circuits and issued the report[9]- "Harmonics and Electrical Noise in Distribution Systems, Volume 1: Measurements and Analyses". This report looks at over 100 distribution circuits within 10 utilities in the US and characterizes the noise environments of the circuits. Both time domain and frequency domain noise is captured and described. Both conducted and radiated noise are examined over frequencies from power line harmonics up to 1 GHz. Sources of noise are identified in some cases. They concluded that the noise environments of the different distribution circuits over the several systems were very similar in nature. This report is therefore useful in establishing feasibility for PLC operation over all distribution systems in North America.

Channel Capacity for a Rural Distribution Circuit

The channel selected for characterization is a feeder out of the Blanche Substation of the Fayetteville Electric Service in Tennessee. The substation is fed with 46 kilovolts and has two distribution circuits leaving. One of the distribution circuits is a new construction with 26 kv distribution voltage. The distribution circuit being characterized is an older 13.8 kv circuit. This circuit leaves the substation and travels almost a mile before a drop or branch circuit. Couplers to all three phases were installed as the circuit leaves the substation and also near the first branch of the circuit about a mile away. Three additional sets of couplers were installed at other intermediate locations along the distribution circuit. These are at approximately 2.0, 3.5, and 5.5 miles from the substation. The entire length of the distribution circuit is about 8 miles.

Several sets of measured data were used to build a simulation for a PLC that would operate between the substation and the first circuit branch about a mile away. The mile long feeder transmission line consists of four 4/0 conductors in horizontal ABNC configuration with approximately 4 foot spacings. The R, L, C, and G parameters were determined for this transmission line up to about 150 MHz and its ABCD parameters were created from this information. Unique coupling arrangements[10], consisting of grounded lightning arresters with ferrite elements on their ground conductors, were simulated at either end of the mile long transmission line. Since coax drop cables were used to couple from the ground, these were also included in the end to end transmission path in the simulation. A typical set of distribution drop hardware including a single phase distribution transformer, a lightning arrester, and a fusible disconnect were

interconnected. The impedance of this combination was measured from 30 Hz up to over 130 MHz. These "drops" were used to create an additional mile of loaded transmission line as a load for the first mile feeder.
This loaded transmission line used AWG2 conductors arranged in a CBA configuration over a AWG2 neutral with a combination of "drops" at the main line and also others "bridge-tapped" on with 500 foot branch circuits to the "drops". From this simulated channel the transmission loss was calculated. Actual transmission measurements were made to assure the validity of the simulations.

Noise data was gathered from all the couplers installed on the distribution circuit. This included both power spectra and transient impulse noise measurements. Figure 1 illustrates one noise power spectrum recorded at the first branch of the distribution circuit. This record is used as the reference for estimating the channel capacity over the distribution circuit from the substation to this test point. From this figure the low frequency harmonic content is lumped with the AM radio induced noise giving rise to a peak in the lowest spectral power bins. Additional spectral peaks may be seen at about 14 MHz and 18 MHz and these could be from an Amateur Radio transmission since they appeared and disappeared erratically. They could also have been due to some other sources of impulse noise on the circuit. The FM radio band is clearly represented in this noise spectrum.

Figure 2 shows the simulated received power spectrum overlaid onto the spectrum of the reference noise spectrum. The transmit power was set at -40 dBm/Hz over each 1 MHz channel. This corresponds to about 17 dBVrms applied to the line with characteristic impedance of about 460 ohms. It is easy to see the SNR, and identify regions of useable and unusable frequency spectrum from this view. Data from these curves are used together to derive a channel capacity estimate. All 1MHz bands which overlap Amateur Radio bands have been excluded, as well as the channels over the FM band. A 6 dB margin is allowed for variations in SNR over time for each channel. The number of remaining usable channels over the range from 1 MHz up to 130 MHz is found to be 90. The total channel capacity is estimated to be over 770 Mbps. It is also possible from this calculation to determine the type of modulation that might be needed to maximize the channel utilization. Table 1 summarizes this calculation along with two other sets of values obtained assuming lower transmit power densities. With transmit power density of -60 dBm/Hz, or 0 dBm per 1MHz subchannel, the estimated total capacity is still about 280 Mbps. These are encouraging maximum bit rates, however some practical concerns have been neglected. This channel does not have either power loads or communications loads, which must exist and must be considered beyond the feeder. These will consume communications signal power.

Signal Level (dBVrms)	(dBm/Hz)	Number of Useable Channels	Total capacity (Mbps)
17.	-40.	90	770.8
7.	-50.	74	501.4
-3.	-60.	60	280.4

Table 1. Channel Capacity for the First Mile Feeder

Existing power loads on the transmission line will affect the operation of the PLC system. The channel capacity will be reduced especially in urban environments as more loads are connected over shorter distances. Table 2 shows the effects on capacity with only five "typical" power loads per phase per mile added to the simulated first mile feeder. At the power density of -60 dBm/Hz, the capacity drops below 100 Mbps and only 34 channels are operative.

Signal Level (dBVrms)	(dBm/Hz)	Number of Useable Channels	Total capacity (Mbps)
17.	-40.	72	464.3
7.	-50.	57	250.0
-3.	-60.	34	95.8

Table 2. Channel Capacity for the Second Mile with 5 typical "drop" loads

Broadband Data Communications Demo

Demonstration of the feasibility of the broadband communications was established by creating a full-duplex, 2 Mbps, IP connection over the 13.8 kv distribution circuit studied. RF channels at 17 and 83 MHz were used for the two directions of communication. QPSK modulation was used over about 1 MHz of bandwidth in each direction. An NT server was setup at the substation along with modem, RF channel selector, and other communications system hardware. A remote communications station was established at a remote pole with modem transceiver and a portable PC. Coupling onto the power line was by means of a unique, efficient, patented[10] coupling circuit. Video clips of up to 30 Mbytes were requested at the remote PC and they were downloaded error free using TCP/IP on the data stream using FTP client software.

Summary and Conclusions

Channel capacities for rural distribution circuits exceed 200 M bps and will allow multimedia communications to be established. Several problems must be addressed before the technology can be widely deployed [11]. Emissions measurements must be made over many distribution circuit configurations in order to guarantee system compliance. Basic parametric data for installed power cable and power loads must be characterized for use at the RF frequencies of the PLC system. Deregulation of the power utility industry will drive the development and deployment of the new RF PLC systems.

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(US Pat.No. 6,040,759 Issued March, 2000.)

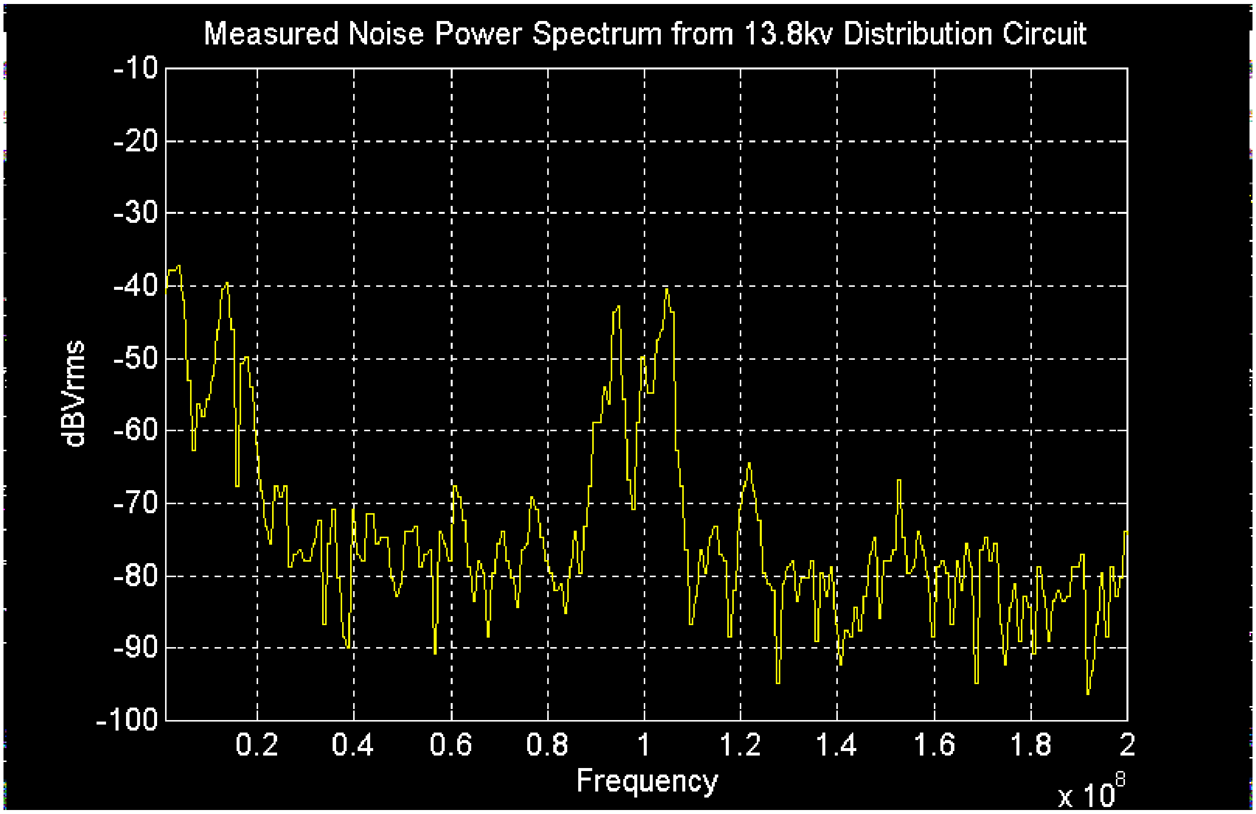

Figure 1. Measured Noise Power Spectrum at Coupler Output 1.0 mile from Substation.

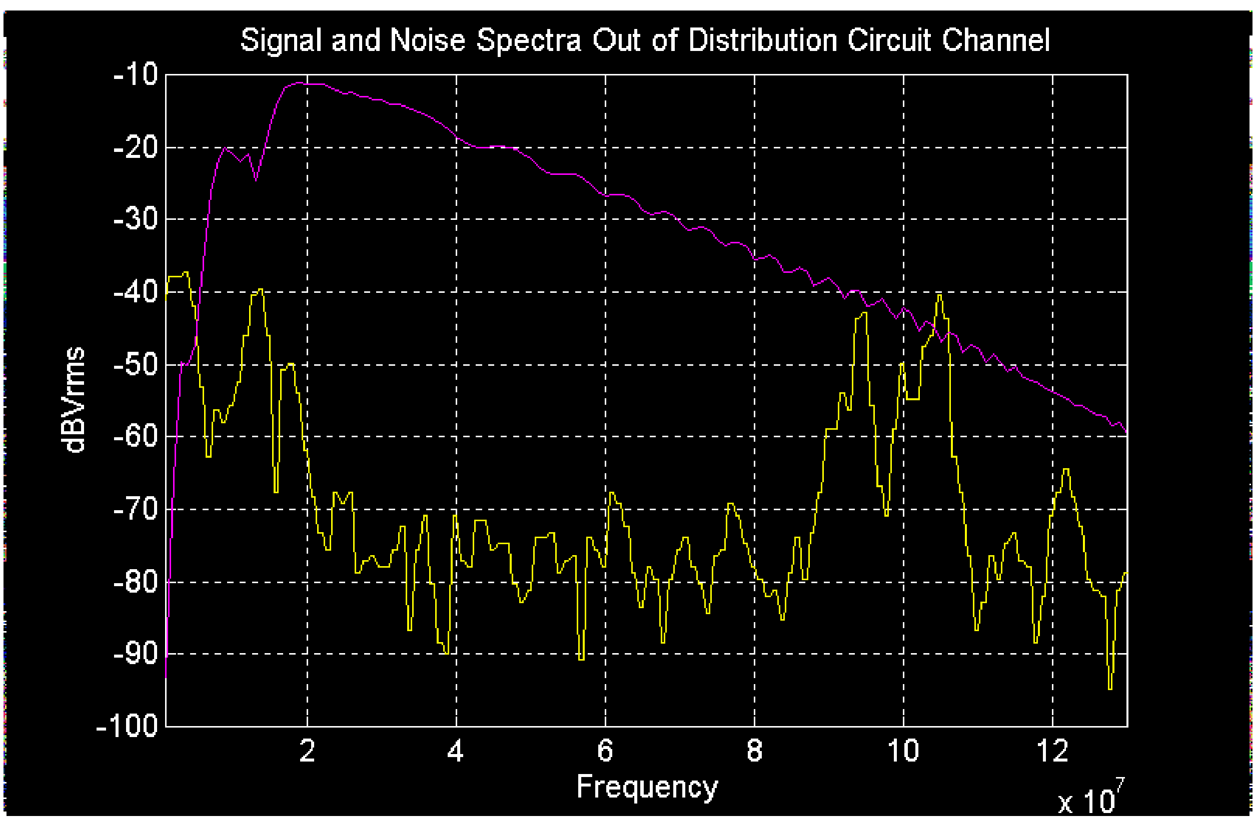

Figure 2. Signal and Noise Out of Coupler, 1.0 mile from Substation.